



Atty. Dkt. No. 087258-0301

Appl. No. 10/631,831

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES**

Appellants: Damien CAMELOT, *et al.*

Title: ENCAPSULATED CRYSTALLINE LACTIC ACID

Appl. No.: 10/631,831

Filing Date: 08/01/2003

Examiner: Helen F. Pratt

Art Unit: 1761

Confirmation 1704  
Number:

**BRIEF ON APPEAL**

Mail Stop Appeal Brief - Patents  
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Sir:

In response to the Office Communication mailed January 16, 2008, the application number in the upper right hand corner of the Appeal Brief has been corrected and now reads 10/631,831. Entry and consideration of the Appeal Brief is respectfully requested.

Under the provisions of 37 C.F.R. § 41.37, this Appeal Brief was filed on November 27, 2007, together with a credit card payment in the amount of \$510.00 covering the fee for filing this Brief under 37 C.F.R. 41.20(b)(2). If these fees are deemed to be insufficient, authorization is hereby given to charge any deficiency (or credit any balance) to our deposit account 19-0741.

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**I. REAL PARTY IN INTEREST**

The real party in interest is Purac Biochem B.V.

**II. RELATED APPEALS AND INTERFERENCES**

Appellants are unaware of any related appeal or interferences.

**III. STATUS OF CLAIMS**

Claim 6 is canceled and claims 1-27 are pending. Claim 17 is withdrawn. Hence, claims 1-5, 7-16 and 18-27 are under consideration, rejected, and appealed.

**IV. STATUS OF AMENDMENTS**

Appellants have made no amendments to the claims after the Final Office Action mailed March 29, 2007. All amendments have been entered.

**V. SUMMARY OF CLAIMED SUBJECT MATTER**

There are three independent claims on appeal, all of which are directed to a novel encapsulated particle comprising crystalline lactic acid and a wetting agent; and methods of using and preparing same. A concise explanation of the subject matter defined by these three independent claims is provided below.

**Claim 1:** Claim 1 is drawn to a “composition comprising an encapsulated particle comprising crystalline lactic acid and a wetting agent.” (Specification at page 4, lines 10-11.)

**Claim 15:** Claim 15 is directed to a method of preparing a food product comprising adding encapsulated crystalline lactic acid particles to the food product whereby “the color, flavor, or shelf-life of the food product is enhanced compared to a similar food

product prepared without adding lactic acid.” (Specification at page 5, lines 4-7.) The encapsulated crystalline lactic acid particles comprise crystalline lactic acid and a wetting agent.

**Claim 18:** Claim 18 is drawn to a method of preparing encapsulated crystalline lactic acid particles. The method comprises (a) preparing crystals of lactic acid; (b) treating the crystals with a wetting agent prior to or during encapsulation; and (c) coating the crystals with an encapsulating coating material. (Specification at 5, lines 10-13.)

## **VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL**

Appellants present a single ground of rejection for consideration on appeal. Specifically, Appellants present for consideration the rejection of claims 1-5, 7-16 and 18-27 under 35 U.S.C. 103(a) as allegedly obvious over European Patent No. 0699392 to Chung, *et al.* (“Chung”) or U.S. Patent No. 6,153,236 to Wu, *et al.* (“Wu”) or U.S. Patent No. 4,537,784 Percel, *et al.* (“Percel”) in view of Borsook, H., *et al.*, “The Preparation of Crystalline Lactic Acid,” Kerckhoff Laboratories of Biological Sciences, California Institute of Technology, Pasadena, CA, June 7, 1933, pages 449-460 (“Borsook”) and Schouten *et al.*, “Low Temperature Crystal Structure and Molecular Conformation of L(+) Lactic Acid,” *J. Mol. Structure*, 323: 165-168 (1994) (“Schouten”).

## **VII. ARGUMENT**

Neither Chung, Wu, or Percel (the “primary references”) in view of Borsook and Schouten (the “secondary references”) renders the claimed invention obvious for at least two reasons. First, there is no *prima facie* case of obviousness because there is no motivation to combine the references. Moreover, given the disclosures of the primary references, one of

skill in the art would have no reasonable expectation of success in obtaining the claimed invention following the collective teachings of the cited references. The entire rejection is based on the rationale that because Chung, Wu, and Percel suggests encapsulated lactic acid compositions, one of skill in the art would have found obvious to substitute crystalline lactic acid, for liquid lactic acid. Such reasoning runs afoul of explicit evidence to the contrary, and therefore cannot adequately support the obviousness rejection. Second, any *prima facie* case of obviousness has been rebutted by showing unexpected results. Indeed, the claimed invention provides an encapsulated particle comprising crystalline lactic acid and a wetting agent composition that provides a number of unexpected properties and advantages as compared to traditional encapsulated lactic acid compositions.

**A. The Examiner Has Failed to Establish a Prima Facie Case of Obviousness**

A *prima facie* case of obviousness requires three basic criteria to be met.<sup>1</sup> First, there must be some suggestion or motivation to modify the references or to combine reference teachings in such a way as to arrive at the claimed invention.<sup>2</sup> Second, one of skill in the art must have a reasonable expectation of success in combining or modifying the references in the way suggested.<sup>3</sup> Finally, the prior art references must teach or suggest all the claim limitations when combined.<sup>4</sup>

Here, there is no *prima facie* case of obviousness because the appealed rejection fails to satisfy at least two of the basic criteria. First, there is no suggestion or motivation to modify the references in the manner argued by the Examiner. Second, given the disclosures

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<sup>1</sup> See MPEP § 2142; *see also In re Vaeck*, 947 F.2d 488, 493, 20 USPQ.2d 1438, 1442 (Fed. Cir. 1991).

<sup>2</sup> *Id.*

<sup>3</sup> *Id.*

<sup>4</sup> *Id.*

of the cited references, one of skill in the art would not have a reasonable expectation of success in modifying the references as suggested by Examiner. Thus, the obviousness rejection cannot be sustained.

**1. The Prior Art Lacks Motivation To Combine Chung, Wu, or Percel with Borsook and Schouten**

Chung, Wu and Percel disclose encapsulated particles (*e.g.*, food acids and/or oils). None of these references, however, teach or disclose an encapsulated particle comprising *crystalline* lactic acid and a wetting agent. The Examiner appears to recognize this deficiency, at least with respect to Chung and Wu.<sup>5</sup> With respect to Percel as well, the Examiner appears to acknowledge that the reference does not expressly teach the use of crystalline lactic acid, but the Examiner alleges “the lactic acid is seen as being crystalline as it is anhydrous and if it is on a carrier no water is seen to make it not crystalline.”<sup>6</sup>

Appellants respectfully submit that the Examiner has improperly convoluted two scientific concepts in likening “crystalline” to “anhydrous.” *To wit*, “dry” or “powdered” lactic acid is not necessarily the equivalent of “crystalline” lactic acid. A substance is not rendered “crystalline” merely because it is anhydrous, and in fact, many crystalline substances, particularly those that are very hygroscopic such as crystalline lactic acid, can contain water.

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<sup>5</sup> Chung describes coating of various “leavening acid cores” with a “barrier material”. While four suitable organic acids are listed, notably, lactic acid is not mentioned. Page 4, 2<sup>nd</sup> paragraph. Similarly, at col. 4, lines 54-56, Wu explicitly states: “Lactic acid, *being a liquid*, is first applied to a carrier such as calcium lactate and converted to a dry solid form.” (Emphasis added.)

<sup>6</sup> Office Action mailed March 29, 2007 at 2.

In an attempt to cure this deficiency, the Examiner introduces Borsook and Schouten for the proposition that crystalline lactic acid particles are well known. However, a prior art reference must be considered in its entirety, including disclosures that teach away from the claims.<sup>7</sup> In fact, “[i]t is improper to combine references where the references teach away from their combination.”<sup>8</sup> Appellants respectfully submit that the present combination of references in the alleged *prima facie* case for obviousness does not heed this admonition.

Appellants have made clear that the mere existence of crystalline lactic acid in the art is not disputed. Rather, Appellants respectfully submit that the use of crystalline lactic acid for the claimed compositions and methods were heretofore unknown, unappreciated, and unobvious.

Percel, for example, sets forth the state of the art at the time the present invention was conceived: “Lactic acid in crystalline form is very deliquescent and when exposed to atmosphere quickly liquefies. It has thus been impossible to use crystalline lactic acid for meat acidulation.”<sup>9</sup> In view of the “impossibility” of encapsulating liquid lactic acid, the art taught that lactic acid had to be adsorbed onto a solid carrier (*e.g.*, calcium lactate), which could then be processed. Accordingly, Percel teaches the use of *liquid* lactic acid sprayed onto a solid carrier.<sup>10</sup>

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<sup>7</sup> See MPEP § 2141.02(VI); *see also W.L. Gore & Associates, Inc. v. Garlock, Inc.*, 721 F.2d 1540, 220 USPQ 303 (Fed. Cir. 1983), *cert. denied*, 469 U.S. 851 (1984).

<sup>8</sup> See MPEP § 2145(X)(D)(2)

<sup>9</sup> Percel at col. 2, lines 13-16.

<sup>10</sup> *Id.* at col. 4, lines 5 – 27.

The remaining primary references are consistent with the disclosure of Percel. Wu teaches that “lactic acid, being a liquid, is first applied to a carrier such as calcium lactate and converted into a dry solid form.”<sup>11</sup> Chung describes coating of various “leavening acid cores” with a “barrier material.”<sup>12</sup> Most telling is that while four suitable organic acids are listed, notably, lactic acid is not mentioned.<sup>13</sup>

In short, the cited primary references belie the Examiner’s assertion that it would have been obvious to a person of ordinary skill in the art at the time the invention was made to substitute crystalline lactic acid for lactic acid. In fact, the references teach the opposite, which undermines the alleged determination of obviousness.

The MPEP uses the following example below to illustrate an improper combination of references. Because the illustration bears directly on the current facts, the example is reproduced below in its entirety:

Claims were directed to a process of producing a porous article by expanding shaped, unsintered, highly crystalline poly(tetrafluoroethylene) (PTFE) by stretching said PTFE at a 10% per second rate to more than five times the original length. The prior art teachings with regard to unsintered PTFE indicated the material does not respond to conventional plastics processing, and the material should be stretched slowly. A reference teaching rapid stretching of conventional plastic polypropylene with reduced crystallinity combined with a reference teaching stretching unsintered PTFE would not suggest rapid stretching of highly crystalline PTFE, in light of the disclosures in the art that teach away from the invention, i.e., that the conventional polypropylene should have reduced crystallinity before stretching, and that PTFE should be stretched slowly.).

Similarly, here, the prior art taught that crystalline lactic acid is “impossible” to encapsulate. Hence, a reference teaching encapsulation of “conventional” lactic acid combined with a reference teaching crystalline lactic acid would not suggest encapsulation of

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<sup>11</sup> Wu at col. 4, lines 54 – 56.

<sup>12</sup> Chung at 4, lines 1 – 8.

<sup>13</sup> *Id.* at lines 9 – 14.



crystalline lactic acid, in light of the disclosures in the art that taught away from the invention.

The Examiner offers no rationale to the contrary. For at least this reason, the Office has failed to provide a proper rationale to combine the cited references in a manner to arrive at the presently claimed invention.

**2. One Of Skill In The Art Would Not Have A Reasonable Expectation Of Success In Combining Chung, Wu, Or Percel With Borsook And Schouten**

Even if, *arguendo*, the cited combination of references is deemed proper, such a combination would not have lead a person of ordinary skill in the art to have a reasonable expectation of success in making the combination to arrive at the present invention. To the contrary, one of ordinary skill in the art would have found explicit disclosure, all of which teaches *away* from the inventive composition.

While “[o]bviousness does not require absolute predictability of success,” obviousness does require “a reasonable expectation of success.”<sup>14</sup> Further, “there can be little better evidence negating an expectation of success than actual reports of failure.”<sup>15</sup> Percel provides precisely this type of evidence, because it confirms that it had been “impossible” to use crystalline lactic acid in encapsulated form. Such demonstrated failures deprive one of skill in the art from enjoying any reasonable expectation of success and offer, at best, a mere hope for success.

The absence of a reasonable expectation of success is further underscored by the Examples of the cited references, none of which use crystalline lactic acid. As noted above,

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<sup>14</sup> *In re O’Farrell*, 853 F.2d 894, 903-04 (Fed. Cir. 1988).

for example, while Wu lists four suitable organic acids are listed, lactic acid is notably absent from the listing.<sup>16</sup> Such evidence of record mitigates against any finding of a reasonable expectation of success.

Taken together, Appellants respectfully submit that neither Chung, Wu nor Percel teaches the use of *crystalline* lactic acid, but rather expressly teach away from its use. Hence, one of skill in the art simply would not have a reasonable expectation of success in modifying Chung, Percel, or Wu as argued by the Examiner, at least because the very references used to support the alleged *prima facie* case for obviousness either expressly and/or impliedly warn against the use of crystalline lactic acid in arriving at the claimed invention.

#### **B. The Claimed Invention Results In Unexpected Results**

“A *prima facie* case of obviousness based on structural similarity is rebuttable by proof that the claimed compounds possess unexpectedly advantageous or superior properties.”<sup>17</sup> In this case, Appellants have rebutted any *prima facie* case by showing unexpected results. Specifically, by using crystalline lactic acid, the present inventors have surprisingly succeeded in encapsulating lactic acid particles without the need for a substrate.<sup>18</sup> The heretofore art required the use of solid carriers to absorb liquid lactic acid.<sup>19</sup> However, the use of solid carries limits the amount of lactic acid that can be encapsulated. Hence, the lactic acid content of the inventive particles can be higher than previously possible, and the

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<sup>15</sup> See, e.g., *Boehringer Ingelheim Vetmedica, Inc. v. Schering-Plough Corp.*, 320 F.3d 1339, 1354, 65 USPQ.2d 1961, 1972 (Fed. Cir. 2003).

<sup>16</sup> Chung at 4, lines 9 – 14.

<sup>17</sup> See M.P.E.P. § 2144.09 (citing *In re Papesch*, 315 F.2d 381, 391, 137 USPQ 43, 51 (CCPA 1963)).

<sup>18</sup> Spec. at page 5, lines 17-20.

<sup>19</sup> See generally Wu.

activity of the lactic acid is not impaired by any substrate.<sup>20</sup> Furthermore, the encapsulated solid lactic acid particles according to the invention are easy to handle and are less expensive than encapsulated liquid lactic acid.<sup>21</sup> The success of the invention was not expected from the prior art and rebuts a *prima facie* case of obviousness.

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<sup>20</sup> Spec. at page 5, lines 17-20.

<sup>21</sup> Spec. at page 5, lines 20-22; page 11, lines 1-5.

### VIII. Conclusion

The rejection of claims 1-5, 7-16 and 18-27 under 35 U.S.C. § 103(a) as allegedly obvious over Chung, Wu, or Percel in view of Borsook and Schouten is untenable because a *prima facie* case of obviousness has not been established. Indeed, the prior art lacks a motivation to combine the cited references in a manner to arrive at the claimed invention, and the prior art belies any expectation of success. Even if a *prima facie* case of obviousness had been established, Appellants have rebutted that case by succeeding unexpectedly in encapsulating lactic acid particles in the absence of a substrate. Thus, Appellants request that the Honorable Board reverse the outstanding final rejections of the claims.

Respectfully submitted,

Date January 28, 2008

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**CLAIMS APPENDIX**

Presented below is a copy of the claims involved in the appeal.

1. (Previously presented) A composition comprising an encapsulated particle comprising crystalline lactic acid and a wetting agent.
2. (Original) The composition of Claim 1 wherein the crystalline lactic acid particle comprises crystalline L(+)lactic acid.
3. (Original) The composition of Claim 1 wherein the crystalline lactic acid particle is encapsulated within a food-grade coating material comprising oil, fat, wax, carbohydrate, protein, polymer, or a mixture thereof.
4. (Original) The composition of Claim 3 wherein the food-grade coating material has a melting point between about 35 and 90C.
5. (Original) The composition of Claim 1, wherein the food-grade coating material is a vegetable oil.
6. (Canceled)
7. (Previously presented) The composition of Claim 1 wherein the wetting agent is silica, starch, calcium lactate, methyl cellulose, or a combination thereof.
8. (Previously presented) The composition of Claim 1 further comprising silica powder as the wetting agent and a partially hydrogenated fraction of a palm oil melting at 61C as an encapsulating coating.
9. (Original) The composition of Claim 1 wherein the encapsulated particle comprises up to 95%(w/w) lactic acid based on the total weight of the encapsulated particle.

10. (Original) The composition of Claim 8 wherein the coating material or coating material plus wetting agent represents about 5 to 70%(w/w) of the encapsulated particle.
11. (Original) The composition of Claim 8 wherein the coating material or coating material plus wetting agent represents about 30 to 60%(w/w) of the encapsulated particle.
12. (Original) The composition of Claim 1 wherein, upon dispersion in water at room temperature, less than 10%(w/w) of the lactic acid is released into the water after 60 minutes.
13. (Original) A food product composition comprising the encapsulated crystalline lactic acid particle of Claim 1.
14. (Original) The food product composition of Claim 13 wherein the food product comprises a comminuted meat product, a bakery product, or an acid-sanded candy.
15. (Previously presented) A method of preparing a food product comprising adding encapsulated crystalline lactic acid particles comprising crystalline lactic acid and a wetting agent to the food product whereby the color, flavor, or shelf-life of the food product is enhanced compared to a similar food product prepared without adding lactic acid.
16. (Original) The method of Claim 15 wherein the food product comprises a comminuted meat product, a bakery product, or an acid-sanded candy.
17. (Withdrawn)
18. (Previously presented) A method of preparing encapsulated crystalline lactic acid particles comprising:
  - preparing crystals of lactic acid;
  - treating the crystals with a wetting agent prior to or during encapsulation; and
  - coating the crystals with an encapsulating coating material.

19. (Original) The method of Claim 18 wherein the lactic acid crystals are about 200 to 800 microns in size.
20. (Original) The method of Claim 18 wherein the lactic acid crystals are encapsulated using a top-spray fluid bed coater.
21. (Previously presented) The method according to claim 18 wherein the wetting agent is silica, starch, calcium lactate, methyl cellulose, or a combination thereof.
22. (Previously presented) An encapsulated particle comprising crystalline lactic acid and a wetting agent.
23. (Previously presented) The encapsulated particle of claim 22 wherein the crystalline lactic acid particle comprises crystalline L(+)-lactic acid.
24. (Previously presented) The encapsulated particle of claim 22 wherein the crystalline lactic acid particle is encapsulated within a food-grade coating material comprising oil, fat, wax, carbohydrate, protein, polymer, or a mixture thereof.
25. (Previously presented) The encapsulated particle composition of claim 24 wherein the food-grade coating material has a melting point between about 35 and 90 °C.
26. (Previously presented) The encapsulated particle of claim 22, wherein the food grade coating material is a vegetable oil.
27. (Previously presented) The encapsulated particle of claim 22, wherein the wetting agent is silica, starch, calcium lactate, methyl cellulose, or a combination thereof.

**EVIDENCE APPENDIX**

Applicants attach hereto the following references.

**Evidence Entered by Examiner and Relied on by Appellant in Appeal Brief**

European Patent No. 0699392 to Chung, *et al.* ("Chung") (Cited by Appellants in Form SB/08 of IDS filed December 1, 2004, which was entered into record by Examiner on November 14, 2006 and attached to Office Action dated November 17, 2006.)

U.S. Patent No. 6,153,236 to Wu, *et al.* ("Wu") (Entered into record by Examiner on November 17, 2006 in accordance with Form 892, attached to Office Action dated November 17, 2006.)

U.S. Patent No. 4,537,784 Percel, *et al.* ("Percel") (Cited by Appellants in Form SB/08 of IDS filed December 1, 2004, which was entered into record by Examiner on November 14, 2006 and attached to Office Action dated November 17, 2006.)

**Evidence in Addition to Above References Relied Upon by Examiner as to Grounds of Rejection to be Reviewed Upon Appeal**

Borsook, H., *et al.*, "The Preparation of Crystalline Lactic Acid," Kerckhoff Laboratories of Biological Sciences, California Institute of Technology, Pasadena, CA, June 7, 1933, pages 449-460 ("Borsook") (Entered into record by Examiner on November 17, 2006 in accordance with Form 892, attached to Office Action dated November 17, 2006.)

Schouten *et al.*, "Low Temperature Crystal Structure and Molecular Conformation of L(+) Lactic Acid," J. Mol. Structure, 323: 165-168 (1994) ("Schouten") (Cited by Appellants in Form SB/08 of IDS filed December 1, 2004, which was entered into record by Examiner on November 14, 2006 and attached to Office Action dated November 17, 2006.)



**RELATED PROCEEDINGS APPENDIX**

Appellants are not aware of any related appeals or interferences, so Appellants have no information regarding related proceedings to submit.

(19)



Europäisches Patentamt  
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(11)

**EP 0 699 392 A2**

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(54) **Novel encapsulated leavening acid composition**

(57) A composition of matter comprising:

(a) one or more leavening acids; and

(b) a coating surrounding said one or more leaven-  
ing acids;  
said coating comprising:

(1) a barrier composition; and

(2) a surface active agent or plasticizer material  
is disclosed.

**EP 0 699 392 A2**

**Description**Background of the Invention

## 1. Field of the Invention

The present invention relates to leavening acid compositions for baked goods and more particularly leavening acids which are encapsulated by a composition which includes both a barrier material and a surface active agent.

## 2. Technology Description

Chemical leavening systems have been known for over 100 years. The replacement of yeast to induce process of fermentation by a carbonate alkali which is subjected the neutralizing action of an acid has reduced the amount of time and materials required for the preparation of baked goods. From this early beginning various leavening systems have been invented and sold as baking powders which contain not only the leavening alkali and the acid employed to neutralize the acid, but also fillers which enabled convenient measurement, handling and storage of such baking powders.

Leavening systems have long been known to comprise two basic ingredients. The first, of course, is the leavening acid such as cream-of-tartar, various phosphoric acids such as orthophosphoric acid, pyrophosphoric acid and the partial salts thereof such as monocalcium phosphate, sodium acid pyrophosphate, and any other suitable, edible, non-toxic acid which would not impart an undesirable taste to the resultant baked goods. Such acids have been known as "acidulants", or "baking acids" but more commonly as "leavening acids".

When added to a moist batter or dough, the acid reacts with a carbon dioxide liberating compound included in the batter or dough to yield the gas necessary for leavening. The rate of gas evolution is an important consideration determining largely the volume, density and texture qualities which will be imparted to the final baked product. This rate must occur within rather narrow limits for some applications such as in the preparation of prepared, canned dough for biscuits. Also, leavening requirements differ widely among the various baked goods for each of these demands a particular speed of evolution to ensure highest quality products. One of the principal factors with respect to the speed of evolution of carbon dioxide is the reactivity of the carbon dioxide producing material.

It has been known to regulate the speed of carbon dioxide evolution by control of the reactivity of the leavening acid. Numerous attempts to control the speed of reaction of the leavening acid are known in the art. Typical examples include U.S. Pat. No. 3,034,899 to Tucker wherein a finely divided calcium salt is combined with the acid to control the speed of reaction.

Calcium salts have been employed in chemical leavening systems from its earliest days. A typical example of such use is found in U.S. Pat. No. 315,831 to Peters. However, such calcium salts as taught in Peters are relatively slow acting and have not provided satisfactory performance as the carbonate factor particularly in comparison with the alkali metal salts. Although calcium salts such as calcium carbonate have been employed for various purposes such as preservatives for the leavening acid, etc. as noted in U.S. Pat. Nos. 4,388,336 and 4,526,801, such carbonates do not provide the reactivity desired for a carbonate factor in baked goods.

U.S. Patent No. 3,492,128 discloses the coating of citric, fumaric, adipic, tartaric, or malic acids or glucconic-delta-lactone with hydrogenated peanut, cottonseed, coconut, babassu, or tucum oils so that the oil comprises about 15% of the total weight. A granular mixture is produced wherein the leavening acids remains inactive until the melting point of the coating material is reached during baking.

ES 8401775 is directed to coating fine particles of sodium bicarbonate raising agent with a solution of a cellulose ether mixture consisting of (1) hydroxypropylmethyl cellulose with 4-12% 2-hydroxypropyl groups, and (2) ethyl cellulose with 45-49.5% ethoxy groups. An acidic raising agent is coated with the same composition and two coated powders are mixed in approximately stoichiometric amounts. The moisture content of the baking powder is below 5%.

JP 60-141227 is directed to an acidic agent coated with a sparingly water-soluble substance. Acidic agents disclosed include ammonium alum, burnt ammonium alum, alum, burnt alum, fumaric acid, ammonium chloride, glucono-delta-lactone, acidic potassium pyrophosphate, tartaric acid, potassium tartarate, sodium fumarate, potassium hydrogentartarate and potassium phosphate.

It is a primary objective when using leavening acids to modulate and control the carbon dioxide liberation kinetics to yield a suitable final baked good product. More particularly, it is desirable to limit the reactive effect of water with the leavening acid. Ideally, the leavening acid would be designed so that it would not be reactive at the time of kneading or cold storing of the dough but would be reactive during heating, where the leavening of the final product takes place.

Particularly useful leavening acids are phosphate materials, and more specifically monocalcium phosphate. This acid is considered desirable as a commercial candidate as it does not possess sodium. While monocalcium phosphate does not possess sodium it has been difficult to adequately control its reaction rate which results in the release of carbon dioxide bases at various stages during the baking cycle. the fundamental problem with the use of monocalcium phos-

phate is that it liberates gas at too fast a desired rate. As a result, its commercial use has generally been limited to being a part of a leavening acid blend. Such blends can be less than optimal because they either may contain sodium, for example blends of monocalcium phosphate with sodium aluminum phosphate or sodium pyrophosphate, or may not have a completely bland taste.

The use of so-called "coated" monocalcium phosphate where the monocalcium phosphate has a thin coating of phosphate surrounding its acid core is known in the art. However, the "coating" does not provide the reaction kinetics that is ideally preferred and typically can only be used as part of a blend composition.

Accordingly, it would be desirable to produce a monocalcium phosphate leavening acid whose release rate properties can be tightly controlled for optimal use for a multiple of baking applications.

#### Brief Summary of the Invention

In accordance with the present invention, leavening acid compositions which have excellent controlled release properties for reaction with leavening bases during various stages in the baking of baked goods are provided. The acid compositions are particularly characterized by being encapsulated in a material which enables the desired release properties.

One embodiment of the present invention comprises a composition of matter comprising:

(a) one or more leavening acids; and

(b) a coating surrounding said one or more leavening acids; said coating comprising:

(1) a barrier composition; and

(2) a surface active agent or a plasticizer material.

In particularly preferred embodiments, the leavening acid comprises anhydrous monocalcium phosphate, the barrier composition is selected from the group consisting of glyceryl monopalmitostearate; a mixture of ethylcellulose, coconut oil, ammonium hydroxide and oleic acid; and gelatin; and the surface active agent is selected from the group consisting of sucroesters, polyoxyethylene sorbitan esters and mixtures thereof. The coating may also include both a surface active agent and a plasticizer material to further enhance the release properties and the coating is preferably applied to the leavening acid by utilizing fluidized bed encapsulation techniques.

Another embodiment of the present invention comprises a baking mix for preparing an edible baked good including a composition of matter comprising:

(a) one or more leavening acids; and

(b) a coating surrounding said one or more leavening acids; said coating comprising:

(1) a barrier composition; and

(2) a surface active agent or plasticizer material.

The baking mix may be used to prepare a cake, muffin, doughnut, bread, pastry, cookie, brownie, hush puppy, pancake, waffle, pizza crust or roll.

Still another embodiment of the present invention comprises encapsulated monocalcium phosphate wherein the encapsulating material is not solely a phosphate.

Accordingly, it is an object of the present invention to provide a composition useful as a leavening acid which has excellent stability and release properties.

It is another object of the present invention to provide a baking mix using the novel leavening acid composition.

These, and other objects, will readily be apparent to those skilled in the art as reference is made to the detailed description of the preferred embodiment.

#### Detailed Description of the Preferred Embodiment

In describing the preferred embodiment, certain terminology will be utilized for the sake of clarity. Such terminology is intended to encompass the recited embodiment, as well as all technical equivalents which operate in a similar manner for a similar purpose to achieve a similar result.

The main focus of the present invention is to develop leavening acid compounds which have desirable control release properties so that the acid would be released only when the proper time in the baking cycle takes place. More particularly, the liberation of carbon dioxide should take place either by an input of water to a baking mixture containing the leavening acid compound, by the elevation of temperature during heating or by the combined effect. Conversely, it is desired that the acid not prematurely release carbon dioxide gas during the preparation of the baking mix, or subsequent dough, for example, during the kneading phase, or while it is being stored prior to baking. The present invention accomplishes the above criteria by encapsulating the leavening acid in a protective coating which includes both a barrier material and a surface active agent and/or plasticizer material.

The leavening acid which forms the core of the core/shell compounds formed in the present invention can be any of the following materials: monocalcium phosphate, monohydrate; monocalcium phosphate, anhydrous; sodium aluminum phosphate; a mixture of sodium aluminum phosphate with monocalcium phosphate; a mixture of sodium aluminum phosphate with aluminum sulfate; sodium acid pyrophosphate; sodium aluminum sulfate; potassium aluminum sulfate; ammonium alums; sodium alums; potassium alums; monosodium phosphate; monopotassium phosphate; tartaric acid; citric acid; fumaric acid; and glucono-delta-lactone.

Particularly preferred is the use of phosphate materials, and in particular monocalcium phosphate, in either its hydrated or, even more preferably, its anhydrous form.

In practice, the core leavening acid comprises between about 50 and about 98 percent by weight of the coated leavening acid compound, preferably between about 75 and about 95 by weight of the compound.

The core leavening acid typically has a mean particle size of between about 20 and about 200 microns, with particle sizes ranging from about 30 to about 120 microns or from about 50 to about 200 microns being commercially available.

The coating material is made from at least a barrier material and a surface active agent and/or plasticizer. The combination of both types of materials results in the production of coatings which are capable of providing the above-described release properties.

The first component of the coating is a barrier material. The primary criteria for selecting suitable barrier materials is that they be food grade materials and are capable of being selectively permeated by water and/or heat to liberate carbon dioxide from the core acid.

Examples of barrier materials which may be selected include the following: fatty acids, polyglycerol esters of fatty acids, monoglycerides, diglycerides, gelatins, starches derived from corn, wheat, potato or milo vegetables, zein proteins, sucroesters, sucroglycerides, cellulose ethers, cellulose esters, chitin, chitosan, amylopectin, hydrocolloids and mixtures thereof.

Specific barrier materials include the following generic materials, along with, where appropriate, trade names that the materials are presently sold under: glyceryl esters of long chain fatty acids such as glyceryl monopalmitostearate (Geleol - Gattefosse Company), glyceryl palmitostearate (Biogapress - Gattefosse Company), and polyglyceryl palmitostearate (Plurol WL1009 - Gattefosse Company); acetylated monoglycerides such as monoacetylated monoglycerides (Myvacet 5-07 - Eastman Kodak Company); hemisynthetic glycerides (Suppocire A and Suppocire D - Gattefosse Company); sucroglycerides derived from fatty oils such as coprah oil (Celynol LMO - Rhône-Poulenc SA), palm oil (Celynol MSPO 11 - Rhône-Poulenc SA), hydrogenated palm oil (Celynol MPSO 11H - Rhône-Poulenc SA), and hydrogenated soybean oil; cellulose acetate phthalate (Aquateric CD910 - FMC Corp.); modified celluloses such as ethylcellulose aqueous dispersions (Aquacoat - FMC Corp.), and hydroxyl propylcellulose (Klucel EF - Aqualon Company); sucrose esters of fatty acids having a HLB value of between about 7-15 such as palmitate (Sucroester 15 - Gattefosse Company), and distearate (Sucroester 11 - Gattefosse Company); mixture of ethylcellulose, coconut oil, ammonium hydroxide and oleic acid (Surelease - Colorcon Company); gelatin (100, 175 and 250 bloom strength); starches such as high amylose corn starch (Hylon VII), pregelatinized corn starch (Ultratex 1), modified corn starch (Ultracet LT), waxy maize starch (Colflo 67), pregelatinized waxy maize starch (Instant Clearjel), modified waxy maize starch (Purity Gum 1773); gums such as carrageenan gum (Carrageenan IOTA), pectin gum (Unipectin HMI), guar gum, locust bean gum, and xanthan gum; long chain fatty acids having a carbon chain length of between about 9 and about 21 carbon atoms such as capric acid, lauric acid, myristic acid, tridecylclic acid; gelatins having a bloom strength of greater than 100 (e.g., 100, 175, 250) and mixtures thereof.

Particularly preferred is the use of glyceryl monopalmitostearate; a mixture of glycerides and one or more fatty acids; a mixture of ethylcellulose, coconut oil, ammonium hydroxide and oleic acid; and sucroglycerides derived from fatty oils.

The other component of the coating is a surface active agent or plasticizer material. These materials can function to reduce the thickness and provide flexibility to the barrier material when applied to the core leavening acid and thereby enable the production of a controlled release material. The key criteria to be considered when selecting such materials is that they be a food grade material and able to provide an optimally sized coating.

More particularly, the surface active agent functions to provide a uniformly distributed coating of the barrier material to produce a strong thin coating whereas the plasticizer functions to help provide coatings which are thin, strong and do not easily break. Particularly preferred is the use of both surface active agents and plasticizer materials.

Examples of surface active agents which may be selected include the following: sucroesters, sucroglycerides, pro-

pylene glycol monoesters, ethoxylated monoglycerides, ethoxylated diglycerides, glycerol lacto ester of fatty acids, lecithin, polyoxyethylene sorbitan esters, sorbitan esters of fatty acids, stearyl-2-lactylate, polyoxyethylene esters of fatty acids such as stearic acid, acetylated monoglycerides and mixtures thereof. Particularly preferred are sucroesters, polyoxyethylene sorbitan esters, specifically polyoxyethylene sorbate monooleate and mixtures thereof. Such materials are commercially available under the names of Sucroester 7 from the Gattefosse Company (sucrose distearate) and Tween 80 (polyoxyethylene sorbate monooleate).

Several of the barrier materials, particularly the sucroesters can additionally function as the surface active agents. Other materials which have multiple functions include mono and diglycerides, polyoxyethylene esters of long chain fatty acids such as polyoxyethylene sorbate monooleate, sorbitan monoesters of long chain fatty acids and gelatins.

Preferred plasticizers include acetyl tributyl citrate (Citroflex A4), acetyl triethyl citrate (Citroflex A2), tricalcium phosphate, dicalcium phosphate and diethylphthalate. These materials function to produce very thin coatings, i.e., the entire coating comprising no more than 2 to about 10 percent by weight of the entire core/shell material.

In practice, the barrier material is between about 80 and about 100 percent by weight of the coating material, and more preferably between about 90 and about 95 percent by weight of the coating material. Further, the coating typically has a thickness ranging between about 3 and about 20 microns, more preferably between about 5 and about 10 microns.

In another embodiment, where monocalcium phosphate is the leavening acid, the coating can take the form of any food grade encapsulating material with the proviso that the encapsulating material not solely be a phosphate material.

To apply the coating to the leavening acid, any method which is commonly used to encapsulate solid food grade materials may be selected. Examples of such methods include fluidized bed coating, coacervation, interfacial polycondensation polymerization, spray coating, pan coating, solvent film coating, and the like. Particularly preferred is the use of fluidized bed coating.

Under such a coating method, the core leavening acid, typically in the form of a powder is placed in a fluidized bed apparatus, preferably equipped top or bottom spray nozzles. A dispersion containing the coating material is then pumped into and atomized in the apparatus on the fluidized particle bed, typically by a hot air current. In practice, the solvent used to form the coating dispersion is typically water, although other solvents such as alcohols and glycols could be used.

The application of the dispersion to the powder typically takes between 15 minutes and 4 hours, depending on the thickness of the coating film desired. The coated material powder is then dried, typically for between about 1 minute and 1 hour, resulting in the production of a coating of the coating material onto all external surfaces of the leavening acid core.

In practice the core does not react with the coating and therefore, two discrete phases (e.g., core/shell particle morphology) are produced.

Once produced, the novel leavening acid compositions of the present invention may be incorporated in baking mixes for food products where the acids react with bases, typically sodium bicarbonate, to produce the leavening function that any known chemical leavening agent or biological leavener such as yeast would ordinarily provide. The inventive chemical leavening system of this invention may be incorporated into a baking powder product conveniently prepared by admixing the acid with an base as a dry powder mix. It is well known that baking powders in the dry powder form are best prepared together with fillers contributing to the bulk of the powder and aiding its measurement for actual use. Fillers such as starch, calcium sulfate or calcium carbonate are generally employed in baking powders of this invention. Conventional preservatives and fillers may be employed together with the baking powder composition of this invention as is known in the art.

Examples of food products which can incorporate the inventive compositions, include, but are not limited to the following: cake, including layer and pound cake; muffin; doughnut; bread; pastry; cookie; room temperature, refrigerated or frozen dough; brownie; hush puppy; pancake; waffle; pizza crust or roll. The food products may be stored at room temperature or at reduced temperatures, e.g., refrigerated or frozen storage conditions.

In use, when the baking mixes are heated, the leavening acids controllably release and react with the bases to produce a properly leavened food product. The use of the inventive coated leavening acids, particularly encapsulated monocalcium phosphate, provides a control release profile such that a particularly high quality leavened product is produced. The present invention enables the use of monocalcium phosphate alone as a leavening acid. This is a significant improvement as it contains no sodium, has a bland taste and reacts slowly enough to provided desired leavening properties.

Fresh dough can be prepared from the leavening systems of this invention in the conventional manner as has been practiced in the art. Typically the ingredients are mixed together in the dry state and may be stored for conventional time periods. It is preferable to refrigerate dry mixed materials if extended time periods occur between mixing and the preparation of the fresh dough. The dry mix is employed to prepare fresh dough by incorporating suitable liquids such as milk and shortening materials as is known in the art.

As is known in the art, the desired pH of the final baked good can be controlled by incorporating into fresh dough leavening acids and alkaline carbonate sources normally employed for that purpose in the art. Generally, the pH of the final baked product ranges from about 5.5 to about 9.0, preferably from about 6.9 to about 7.5. The amount of alkaline

carbonate material added should be sufficient to provide a pH within the above-described ranges. Typically there is included from about 0.3% by weight to about 3% by weight of the edible, alkaline agent, based upon the weight of the powdered ingredients employed.

The invention will be better understood by reference to the following examples.

#### Example 1

Into a 1 liter glass container is placed:

81 g of Geleol

4 g of Sucroester 7

500 g of demineralized water

The mixture is melted at 70-80°C under magnetic agitation then emulsified for 2 min at 80°C with the help of a homogenizer equipped with a mixing blade capable of a mixing speed of 14,000 rpm. To this emulsion, still under magnetic agitation, 300 g of demineralized water, previously heated to 80°C, is added. A homogenous and stable dispersion is obtained which is maintained at a temperature of 80-90°C under agitation.

400 g of monocalcium phosphate (MCP), monohydrate form powder is placed in a GLATT GPC G1 type fluid bed apparatus equipped with top nozzles. The size of the particles of the monocalcium phosphate is between 50 and 200 $\mu$ , inclusive. The preceding dispersion, still maintained at 80-90°C, is then pumped and atomized into the GLATT GPC by a hot air current. The following film forming conditions are applied:

- release of fluidization air : 70 m<sup>3</sup>/h
  - material temperature : 38-40°C
  - atomization air pressure : 2 bar
  - atomization air temperature : 70-75°C
  - discharge of the coating emulsion : 7 g/mn
  - atomization time : 126 mn
  - drying : 10 mn
  - material temperature during drying : 38°C
- Total quantity of atomized emulsion : 886 g

470 g of encapsulated monocalcium phosphate is recovered with a coating level of 17.5% with respect to the final product.

The dough rate of reaction (DRR) is a term that defines the speed of carbon dioxide evolved during mixing and holding of a dough prior to baking. It is determined by measuring the volume of carbon dioxide evolved from a standard dough formulation containing known quantities of leavening acid and baking soda under a constant temperature of 27°C in a modified Chittick Apparatus. The DRR is often used as a guide for selecting the type of leavening acid that is best suited for a particular product application. A low value for the DRR, i.e., less than 50 over 2, 6 and/or 10 minute reaction times, tends to indicate an excellent controlled reaction rate.

To measure the amount of CO<sub>2</sub> liberated upon reaction with sodium hydrogen carbonate for the Example 1 composition, 73.5 parts of a simulated dry dough mix containing flour, nonfat dry milk, salt and shortening, 0.75 parts of NaHCO<sub>3</sub> and 0.93 parts of the Example 1 composition are added to a reaction bomb. 43 parts of water are added and the contents are mixed. Using a Chittick Apparatus the amount of CO<sub>2</sub> evolved as compared to the total amount available to be evolved (DRR) at 2 minutes is 22.2; at 6 minutes is 25.6; and at 10 minutes is 30.0.

As a comparison, the DRR for the uncoated MCP at 2 minutes is 58.1; at 6 minutes is 62.1; and at 10 minutes is 63.0. The DRR for a commercially successful sodium aluminum phosphate leavening acid (Levain - Rhône-Poulenc Inc.) at 2 minutes is 24.0; at 6 minutes is 28.0; and at 10 minutes is 31.0.

To determine if the above Example leavening acid composition would work well in baking mixes, the following yellow cake mix is prepared:

	Cake Flour	236.00 parts
	Granulated Sugar	280.84 parts
5	Shortening	53.57 parts
	Nonfat Dry Milk	18.17 parts
	Egg Yolk Solids	22.89 parts
10	Egg White Solids	9.20 parts
	NaCl	6.37 parts
	Inventive Leavening Acid Composition	6.90 parts
15	Sodium Bicarbonate	5.66 parts
	Pregelatinized Wheat Starch	2.60 parts
	Emulsifier	5.00 parts

20 A batter is made by adding to the mixture first, 170.00 parts of water, then 142.00 parts of water. For one set of cakes, the batter was immediately added to a baking dish and baked at 375°F for 25 minutes to form a yellow cake. For a second set of cakes, the batter was chilled at 41°F for 22 hours then baked according to the above conditions to determine the stability of the encapsulated leavening acids.

25 To determine if the above batters could produce high quality cakes after baking, they were qualitatively and quantitatively analyzed by using the following criteria: Batter Specific Gravity, Batter Condition, Cake Specific Volume, Cake pH, Profile, Cake Color, Grain Consistency, Symmetry, Texture and Presence of Off-Color Specks.

The cake specific volume measured is 3.46, the grain is considered "fine" and the symmetry yields a round top. The remaining properties are evaluated as being excellent. Similar results are obtained for both the immediately baked dough as well as the refrigerated sample.

30 As a first comparison, the cake specific volume measured for the uncoated monocalcium phosphate is 2.50, the grain is considered "coarse" and the symmetry yields a dipped or flattened top. As a second comparison, the cake specific volume measured when using phosphate "coated" monocalcium phosphate is 2.90, the grain is considered "coarse" and the symmetry yields a slightly dipped or flattened top. The lower volumes for cake density, grain type and appearance when using these unencapsulated monocalcium phosphate materials demonstrate that their reaction rate is too rapid for practical use.

35 The cake specific volume measured for a commercially successful sodium aluminum phosphate leavening acid (Levain - Rhône-Poulenc Inc.) is 3.55, the grain is considered "fine" and the symmetry yields a round top. The inventive encapsulated materials perform comparably to this leavening acid.

#### 40 Example 2

Into a 1 liter glass container is placed:

280 g of Surelease, a ready-to-use aqueous solution containing from 24 to 26% dry material composed of:

+Ethylcellulose

45 +Coconut Oil

+Ammonium hydroxide

+Oleic acid

190 g of demineralized water

The mixture is agitated with a bar magnet at ambient temperature for 30 min.

50 500 g of MCP powder is placed in a GLATT GPC G1 type fluid bed apparatus equipped with a top nozzle. The size of the particles of this powder is between 50 and 200 $\mu$ , inclusive. The preceding suspension, still kept agitated, is then pumped and atomized in the GLATT GPC G1 apparatus by an air current.

The following film forming conditions are applied:

- 55 - release of fluidization air : 70 m<sup>3</sup>/h
- powder temperature : 36-39°C



- atomization air pressure : 2 bar
- atomization air temperature : 24°C
- 5 - discharge of the coating emulsion : 4.9 g/mn
- atomization time : 99 mn
- drying : 6 mn
- 10 - powder temperature during drying : 36°C
- Total quantity of atomized emulsion : 471 g

577 g of coated monocalcium phosphate is recovered with a coating level of 12.6% with respect to the final product.

15 The amount of CO<sub>2</sub> evolved as compared to the total amount available to be evolved (DRR) at 2 minutes is 22.2; at 6 minutes is 25.6; and at 10 minutes is 31.0. Yellow cakes are made using the formulation and conditions discussed in Example 1. The cake specific volume measured is 3.64, the grain is considered "fine" and the symmetry yields a round top. The remaining properties are evaluated as being excellent. Similar results are obtained for both the immediately baked dough as well as the refrigerated sample.

### 20 Example 3

Into a 1 liter glass container is placed:

- 25 - 30 g of sucroglyceride
- 500 g of demineralized water

30 The sucroglyceride is dispersed in the cold water under magnetic agitation then solubilized at 55°C under magnetic agitation. Coating of 500 g of MCP powder takes place using the procedures of Examples 1 and 2.

The following film forming conditions are applied:

- release of fluidization air : 95 m3/h
- 35 - powder temperature : 39-41°C
- atomization air pressure : 2 bar
- atomization temperature : 47°C
- 40 - discharge of the coating emulsion : 6.3 g/mn
- drying : 10 mn
- 45 - powder temperature during drying : 36°C
- Total quantity of atomized emulsion : 533 g

524 g of coated monocalcium phosphate is recovered with a coating level of 20.0% with respect to the final product.

50 The amount of CO<sub>2</sub> evolved as compared to the total amount available to be evolved (DRR) at 2 minutes is 21.0; at 6 minutes is 30.0; and at 10 minutes is 48.0. Yellow cakes are made using the formulation and conditions discussed in Example 1. The cake specific volume measured is 3.57, the grain is considered "fine" and the symmetry yields a round top. The remaining properties are evaluated as being excellent. Similar results are obtained for both the immediately baked dough as well as the refrigerated sample.

### 55 Examples 4-28

The fluidized bed procedures described in Examples 1-3 are used to coat monocalcium phosphate (monohydrate) with several different coating materials. In addition the DRR and Cake Performance Testing as described in Example 1

are performed. The coating materials selected and the values for specific cake volume and DRR at 2 and 6 minutes are shown in Table 1.

TABLE 1

Example	Sp. Vol.	DRR		Compositions
		2 Min.	6 Min.	
4	3.18	46.4	52.8	20.6% Gelatin 250 bloom
5	3.24	42.7	48.5	20.6% Gelatin 250 bloom
6	3.57	23.2	32.0	20.6% Celynol MSPO 11H
7	3.43	36.5	51.3	9.0% Sucroester 7
8	3.36	21.7	29.4	12.5% Geleol, 0.63% Sucroester 7
9	3.11	20.9	34.5	13.5% Geleol, 0.63% Sucroester 7
10	3.38	26.2	45.8	5.97% Geleol, 0.75% Sucroester 7
11	3.54	26.7	47.0	5.97% Geleol, 0.75% Sucroester 7
12	3.45	21.5	33.6	7.86% Geleol, 0.39% Sucroester 7, 3.38% Citroflex A4
13	3.38	22.5	29.0	11.25% Geleol, 0.69% Sucroester 7, 12.5% Citroflex A4
14	3.48	25.7	37.5	15.03% Geleol, 0.82% Sucroester 7, 1.69% Citroflex A4

15	3.54	23.1	31.4	13.46% Biogapress, 3.49% Sucroester 15
16	3.55	22.2	25.5	16.7% Biogapress, 0.82% Sucroester 7
17	3.50	22.9	27.5	16.7% Biogapress, 0.82% Sucroester 7
18	3.24	34.7	52.1	7.13 Biogapress, 0.5 Sucroester 7, 3.06 Citroflex A4
19	3.19	22.5	29.6	15.03 Biogapress, 0.82% Sucroester 7 1.67% Tridecyclic Acid
20	3.47	21.4	26.6	15.03 Biogapress, 0.82% Sucroester 7, 1.67% Myristic Acid
21	3.52	21.6	26.2	15.03 Biogapress, 0.82% Sucroester 7, 1.67% Myristic Acid
22	3.59	24.1	38.1	15.03 Biogapress, 0.82% Sucroester 7, 1.67% Capric Acid
23	3.51	21.9	27.0	15.03% Biogapress,



erties.

Having described the invention in detail and by reference to the preferred embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the appended claims.

## Claims

1. A composition of matter comprising:

(a) one or more leavening acids; and

(b) a coating surrounding said one or more leavening acids; said coating comprising:

(1) a barrier material; and

(2) a surface active agent or plasticizer material.

2. The composition according to claim 1 wherein said coating comprises a plasticizer material and a surface active agent.

3. The composition according to claim 1 wherein said one or more leavening acids are selected from the group consisting of monocalcium phosphate, monohydrate; monocalcium phosphate, anhydrous; sodium aluminum phosphate; a mixture of sodium aluminum phosphate with monocalcium phosphate; a mixture of sodium aluminum phosphate with aluminum sulfate; sodium acid pyrophosphate; sodium aluminum sulfate; potassium aluminum sulfate; ammonium alums; sodium alums; potassium alums; monosodium phosphate; monopotassium phosphate; tartaric acid; citric acid, fumaric acid; and glucono-delta-lactone and mixtures thereof.

4. The composition according to claim 3, wherein said leavening acid comprises monocalcium phosphate, monohydrate or monocalcium phosphate, anhydrous.

5. The composition according to claim 1 wherein said barrier material is selected from the group consisting of fatty acids, polyglycerol esters of fatty acids, monoglycerides, diglycerides, gelatins, starches, zein proteins, chitin, chitosan, amylopectin, hydrocolloids and mixtures thereof.

6. The composition according to claim 5 wherein said barrier material is selected from the group consisting of glyceryl monopalmitostearate, glyceryl palmitostearate, polyglyceryl palmitostearate, monoacetylated monoglyceride, hemisynthetic glyceride, sucroglycerides derived from coprah oil, sucroglycerides derived from palm oil, sucroglycerides derived from hydrogenated palm oil, sucroglycerides derived from hydrogenated soybean oil, cellulose acetate phthalate, ethylcellulose aqueous dispersions, hydroxypropyl cellulose, sucrose palmitate, sucrose distearate, high amylose starch, high amylose waxy starch, pregelatinized starch, modified starch, waxy starch, pregelatinized waxy starch, modified waxy starch, carrageenan gum, pectin gum, xanthan gum, guar gum, locust bean gum, capric acid, lauric acid, myristic acid, tridecylclic acid, gelatins having a bloom strength of greater than 100, and mixtures thereof.

7. The composition according to claim 1, wherein said barrier material is selected from the group consisting of glyceryl monopalmitostearate; a mixture of ethylcellulose, coconut oil, ammonium hydroxide and oleic acid; and sucroglycerides.

8. The composition according to claim 1, wherein said surface active agent is selected from the group consisting of sucroesters, sucroglycerides, propylene glycol monoesters, ethoxylated monoglycerides, ethoxylated diglycerides, glycerol lacto esters of fatty acids, lecithin, polyoxyethylene sorbitan esters, sorbitan esters, stearyl-2-lactylate, polyoxyethylene esters of fatty acids, acetylated monoglycerides and mixtures thereof.

9. The composition according to claim 8 wherein said surface active agent is selected from the group consisting of sucroesters, polyoxyethylene sorbitan esters, monoesters of long chain fatty acids and mixtures thereof.

10. The composition according to claim 2 wherein said plasticizer material is selected from the group consisting of acetyl tributyl citrate, tricalcium phosphate, dicalcium phosphate, and diethylphthalate and mixtures thereof.

11. The composition according to claim 1 wherein said leavening acid comprises between about 50 to about 98 percent by weight of said composition and said coating comprises between about 50 to about 2 percent by weight of said composition, the total weight of said composition being 100 weight percent.

12. The composition according to claim 1 wherein said coating is applied to said leavening acid by a method selected from the group consisting of fluidized bed coating, coacervation, interfacial polycondensation polymerization and solvent film coating.

13. The composition according to claim 12 wherein said coating is applied to said leavening acid by fluidized bed coating.

14. A composition of matter consisting essentially of:

(a) monocalcium phosphate; and

(b) a coating surrounding said monocalcium phosphate, said coating comprising:

(1) a barrier composition; and

(2) a surface active agent or plasticizer material.

15. The composition according to claim 14 wherein said barrier composition is selected from the group consisting of glyceryl monopalmitostearate, glyceryl palmitostearate, polyglyceryl palmitostearate, monoacetylated monoglyceride, hemisynthetic glyceride, sucroglycerides derived from coprah oil, sucroglycerides derived from palm oil, sucroglycerides derived from hydrogenated palm oil, sucroglycerides derived from hydrogenated soybean oil, cellulose acetate phthalate, ethylcellulose aqueous dispersions, hydroxypropyl cellulose, sucrose palmitate, sucrose distearate, high amylose starch, high amylose waxy starch, pregelatinized starch, modified starch, waxy starch, pregelatinized waxy starch, modified waxy starch, carrageenan gum, pectin gum, xanthan gum, guar gum, locust bean gum, capric acid, lauric acid, myristic acid, tridecylclic acid, gelatins having a bloom strength of greater than 100, and mixtures thereof.

16. The composition according to claim 15 wherein said surface active agent is selected from the group consisting of sucroesters, sucroglycerides, propylene glycol monoesters, ethoxylated monoglycerides, ethoxylated diglycerides, glycerol lacto esters of fatty acids, lecithin, polyoxyethylene sorbitan esters, sorbitan esters, stearyl-2-lactylate, polyoxyethylene esters of fatty acids, acetylated monoglycerides and mixtures thereof.

17. The composition according to claim 15 wherein said coating comprises a plasticizer material and a surface active agent.

18. A baking mix for preparing an edible baked good including a composition of matter comprising:

(a) one or more leavening acids; and

(b) a coating surrounding said one or more leavening acids; said coating comprising:

(1) a barrier material; and

(2) a surface active agent or a plasticizer material.

19. The baking mix according to claim 18 which is used to produce a cake, muffin, doughnut, bread, pastry, cookie, room temperature, refrigerated or frozen dough, brownie, hush puppy, pancake, waffle, pizza crust or roll.

20. The baking mix according to claim 18 wherein said coating comprises a plasticizer material and a surface active agent.

21. The baking mix according to claim 18 wherein said one or more leavening acids are selected from the group consisting of monocalcium phosphate, monohydrate; monocalcium phosphate, anhydrous; sodium aluminum phosphate; a mixture of sodium aluminum phosphate with monocalcium phosphate; a mixture of sodium aluminum phosphate with aluminum sulfate; sodium acid pyrophosphate; sodium aluminum sulfate; potassium aluminum sulfate;

ammonium alums; sodium alums; potassium alums; monosodium phosphate; monopotassium phosphate; tartaric acid; citric acid; fumaric acid; and glucono-delta-lactone and mixtures thereof.

22. The baking mix according to claim 21 wherein said leavening acid comprises monocalcium phosphate, monohydrate or monocalcium phosphate, anhydrous.

23. The baking mix according to claim 18 wherein said barrier material is selected from the group consisting of fatty acids, polyglycerol esters of fatty acids, monoglycerides, diglycerides, gelatins, starches, zein proteins, chitin, chitosan, amylopectin, hydrocolloids and mixtures thereof.

24. The baking mix according to claim 23 wherein said barrier material is selected from the group consisting of glyceryl monopalmitostearate, glyceryl palmitostearate, polyglyceryl palmitostearate, monoacetylated monoglyceride, hemisynthetic glyceride, sucroglycerides derived from coprah oil, sucroglycerides derived from palm oil, sucroglycerides derived from hydrogenated palm oil, sucroglycerides derived from hydrogenated soybean oil, cellulose acetate phthalate, ethylcellulose aqueous dispersions, hydroxypropyl cellulose, sucrose palmitate, sucrose distearate, high amylose starch, high amylose waxy starch, pregelatinized starch, modified starch, waxy starch, pregelatinized waxy starch, modified waxy starch, carrageenan gum, pectin gum, xanthan gum, guar gum, locust bean gum, capric acid, lauric acid, myristic acid, tridecylclic acid, gelatins having a bloom strength of greater than 100, and mixtures thereof.

25. The baking mix according to claim 18 wherein said barrier material is selected from the group consisting of glyceryl monopalmitostearate; a mixture of ethylcellulose, coconut oil, ammonium hydroxide and oleic acid; and sucroglycerides.

26. The baking mix according to claim 18 wherein said surface active agent is selected from the group consisting of sucroesters, sucroglycerides, propylene glycol monoesters, ethoxylated monoglycerides, ethoxylated diglycerides, glycerol lacto esters of fatty acids, lecithin, polyoxyethylene sorbitan esters, sorbitan esters, stearyl-2-lactylate, polyoxyethylene esters of fatty acids, acetylated monoglycerides and mixtures thereof.

27. The baking mix according to claim 26 wherein said surface active agent is selected from the group consisting of sucroesters, polyoxyethylene sorbitan esters, monoesters of long chain fatty acids and mixtures thereof.

28. The baking mix according to claim 20 wherein said plasticizer material is selected from the group consisting of acetyl tributyl citrate, tricalcium phosphate, dicalcium phosphate and diethylphthalate and mixtures thereof.

29. The baking mix according to claim 18, wherein said coating is applied to said leavening acid by a method selected from the group consisting of fluidized bed coating, coacervation, interfacial polycondensation polymerization and solvent film coating.

30. The baking mix according to claim 29 wherein said coating is applied to said leavening acid by fluidized bed coating.

31. The baking mix according to claim 18 wherein said composition of matter comprises between about 0.2 to about 4.0 parts by weight of said mix.

32. Encapsulated monocalcium phosphate wherein the encapsulating material is not solely a phosphate material.

## THE PREPARATION OF CRYSTALLINE LACTIC ACID

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On account of its importance in intermediary metabolism, lactic acid was among the first compounds chosen in our plan, which we have described in a previous communication (1), to augment the available data on the free energies of formation of substances significant in biological chemistry. It was necessary for this purpose to obtain pure crystalline lactic acid, free of water, anhydride, and lactide. The only description in the literature of the preparation of crystalline lactic acid is that of Krafft and Dyes (2). Table I shows that the product obtained by their method contains relatively large quantities of anhydro impurities. The subject of the present communication is the description of a method which yields the active isomers of lactic acid in a crystalline state, free of water, anhydride, and lactide, supplemented by the description of two methods of separating the active forms from the commercial syrup.<sup>1</sup> Lactic acid commercially available at present either is in the form of the U.S.P. syrup, which usually exhibits a low optical activity corresponding to the excess it happens to contain, which is variable, of one or the other optical isomer, or is the expensive zinc sarcosylactate. The methods described below now make it possible to obtain easily and quickly and at low cost large quantities of both active isomers in a relatively high degree of purity.

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<sup>1</sup> In this communication the form of lactic acid commonly named sarcosylactate or *d*-lactic acid is designated as *l*(+)- or *l*-lactic acid. The salts of this form are levo- and the free acid dextrorotatory. The opposite form is correspondingly designated as *d*(-)- or *d*-lactic acid. Optically inactive lactic acid is referred to as the *dl* form without any implication regarding its constitution; i.e., whether it is a simple mixture of equal quantities of the two active forms, or a definite compound.



The summary in Table III of some of the physical properties of the free acids prepared by these methods shows that they probably have not been obtained in as pure a state out of solution hitherto. For example, the melting points of the active forms are more than 25° higher than the values given in standard reference works (3, 4). They are also less hygroscopic than they are commonly described.

We shall describe first the preparation of the crystalline free acids from the commercial syrup (which contains as a rule about 50 per cent lactic acid, 30 per cent anhydride and lactide, and 15 per cent water). Briefly, the method consists of fractional distillation followed by fractional crystallization from a mixture of equal volumes of ethyl and isopropyl ethers. The typical procedure was as follows: 200 cc. of syrup were distilled from a 1 liter Claisen flask, first with a water pump at about 60° until most of the water had been driven off, and then, with the outside bath temperature raised to 105°, with an oil pump through two liquid air traps at a pressure of about 0.1 mm. A middle fraction of about 75 cc. was collected and redistilled with the oil pump. The middle fraction from the second distillation, usually about 60 cc., was then set away in ice-salt to crystallize. Even when a large quantity of lactic acid is required, it is preferable to carry out the distillation a number of times with small portions because with large quantities greater losses are incurred during the longer heating required at 105°.

In order to minimize anhydride formation in the syrup and in the vapor through overheating, the side arm of the distilling flask, internal diameter about 2 cm., was fused into the neck about 1 cm. above the bulb and was shielded from the heat of the paraffin bath by asbestos board. For the same reason the filter flask in which the distillate was received was kept at room temperature in a water bath during the collection of the middle fractions.

In about 2 hours the first nuclei of crystals appeared in the second middle fraction set away in ice-salt. Removed then to the temperature of ice and shaken vigorously, the syrup soon became a solid crystalline mass. The product at this stage corresponds to that obtained by Krafft and Dyes. The degree of anhydro impurity present is shown in Table I.

The crystalline lactic acid was now dissolved in an equal volume of a mixture of equal parts of ethyl and isopropyl ethers (dried over

sodium), complete solution requiring about  $\frac{1}{2}$  hour at 37°. After some hours at the temperature of ice-salt, crystallization set in. After another hour, when the contents had become a nearly solid

TABLE I  
*Titration of Twice Distilled Lactic Acid (Kraft and Djes (#))*

Weight	First titration, $N/14$ NaOH	Back titration, $N/14$ NaOH	Total titration, $N/14$ NaOH	Calculated value for pure lactic acid, $N/14$ NaOH	Free lactic acid calculated on basis of sole impurity as	
					Anhydride	Lactide
gm.	cc.	cc.	cc.	cc.	per cent	per cent
1.0447	162.0	1.5	163.5	162.4	93.7	97.2
1.0260	159.2	1.4	160.6	159.5	93.7	97.2
1.0513	163.0	1.5	164.5	163.5	93.7	97.2

TABLE II  
*Titration of Crystalline Lactic Acid*

Specimen	Weight	First titration, $N/14$ NaOH	Back titration, $N/14$ NaOH	Total titration, $N/14$ NaOH	Calculated titration value for pure lactic acid, $N/14$ NaOH
	gm.	cc.	cc.	cc.	cc.
<i>l</i> (+)-Lactic acid prepared by recrystallization of distillate three times from the mixed ethers	0.5004	77.84	0.06	77.90	77.86
	0.6836	106.30	0.04	106.34	106.37
	0.7083	110.09	0.04	110.13	110.21
Same after melting and heating to 56° and crystallizing again	0.9963	154.62	0.16	154.78	154.87
	0.7343	114.10	0.28	114.38	114.15
<i>l</i> (+)-Lactic acid from zinc ammonium salt, recrystallized three times from the mixed ethers	0.4182	65.06	0.05	65.11	65.00
	0.4319	67.05	0.05	67.10	67.08
<i>d</i> (-)-Lactic acid from zinc ammonium salt, recrystallized three times from the mixed ethers	0.5498	85.40	0.00	85.40	85.46
	0.3990	61.95	0.00	61.95	62.02

mass of crystals, they were filtered quickly with suction. The crystallization was repeated three times. After the first crystallization, crystallization began in the subsequent ethereal solutions

immediately on cooling under the tap. After the final recrystallization, the fine white crystals were dried at room temperature in a vacuum desiccator. Titration of this product showed that it contained less than 0.1 per cent of impurities such as water, anhydride, or lactide (Table II).

The fractional crystallization from the mixed ethers effects also a separation of the active isomer, which was in excess in the original syrup (here the *l*(+) form), from the main bulk of inactive material. This was shown by the optical activity of the ethereal mother liquor, which was nearly zero (indicating that no resolution, but only a separation of the excess of active isomer from the inactive form, had occurred), and by the melting point of a mixture of the *l*(+) acid obtained by this method and some *l*(+) acid prepared from the zinc ammonium *l*(+) salt. Separately the melting point of each form was 52.7–52.8°. The mixed melting point was 52.7°. On the other hand, the melting point of an equimolar mixture of the acid obtained by fractional crystallization of the distillate from the crude syrup with that prepared from zinc ammonium *d*(–)-lactate was 16.8° (Table III).

We have not had occasion as yet to try the separation by this method of the *d*(–) acid from a preponderance of the *dl* form because all the commercial syrups we secured contained an excess of the *l*(+) isomer. Nevertheless, we feel confident in recommending the method because the solubility in the mixed ethers of the two active acids prepared from their respective zinc ammonium salts was the same, both being much lower than that of the *dl* form. *dl*-Lactic acid can also be crystallized from the mixed ethers, but the temperature of solid CO<sub>2</sub> is necessary for a good yield, while for the active acids 0° is sufficiently low.

The active acids were also prepared by way of their zinc ammonium salts obtained by resolution of the commercial syrup. The method of resolution employed was essentially that described by Purdie and Walker (5). 1000 cc. of lactic acid syrup were made alkaline to litmus with concentrated ammonia, and then boiled until acid again. This was repeated several times until long boiling was necessary to restore a faint acidity. 560 gm. of zinc *dl*-lactate (air-dried) were now added. The solution was again boiled until all the salt had dissolved, and while still boiling the volume was made up to 2 liters. It was filtered rapidly with suction while

still hot, and then transferred to a clean and dry 4 liter beaker. The beaker was placed in a bath of ice water and stirred. When cool it was seeded with about 0.1 gm. of finely powdered zinc ammonium *l*(+)-lactate. Within a short time after the seed had been thoroughly stirred in, the crystals of the optically active zinc ammonium salt began to cloud the solution. The process was controlled by microscopical examination of the crystals from time to time. The optically active double salt forms short, relatively wide, single, rectangular or square prisms; the inactive salt forms long narrow rods frequently arranged in radiating clusters. The inactive form appeared when the solution was too dilute, or when it was set away at 0–2°. When the syrup was too concentrated, crystallization was very slow, and after 24 hours only a poor yield of active crystals contaminated with the inactive form was obtained. If the solution was too dilute, it was boiled again until a definite quantity of water (determined by weight) was driven off; if too concentrated, it was also boiled, then brought to a definite weight with water, and, after cooling, seeded again. When the conditions were suitable, an abundant quantity of optically active crystals appeared in an hour throughout the solution. The beaker was left to stand overnight at room temperature (15–20°). When microscopical examination showed the copious deposit at the bottom of the beaker to be not more than slightly contaminated with inactive crystals, the supernatant liquor was decanted off and centrifuged. The precipitates in the centrifuge cups and in the beaker were washed three times with 95 per cent alcohol, and, after drying in air, the optical activity of an 8 per cent aqueous solution was measured. The amount of solid remaining undissolved in making the 8 per cent solution was a good measure of the degree of contamination with inactive salt.

After the first batch of active crystals had been separated from the syrup, there was dissolved in it a quantity of zinc *dl*-lactate, equal to the weight of the active double salt obtained, and then it was seeded with the opposite active form. Purdie and Walker and others have reported obtaining large quantities of both active forms by this method of repeated crystallization after seeding alternately with one and then the other active form. In spite of many attempts this method always failed us. Repeatedly on seeding with zinc ammonium *d*(–)-lactate we obtained either the *dl*

form, or large quantities of the  $l(+)$  double salt. From one batch of syrup in three successive crystallizations we obtained over a kilo of the  $l(+)$  double salt, although the last two seedings were with  $d(-)$  double salt. The probable reason for our failure is that the syrup contained too great an excess of the  $l(+)$  isomer. We did succeed in obtaining a small quantity of the  $d(-)$  double salt each time on seeding a virgin syrup with  $d(-)$  seed, although it contained an excess of the  $l(+)$  form.

We found also that when zinc ammonium  $d(-)$ -lactate was mixed with a large quantity of the double salt of the  $dl$  acid, the active salt could be separated out by warming to  $55^{\circ}$  for about an hour and then setting aside at room temperature overnight. We did not succeed in obtaining the double salt of the  $l(+)$  acid by this method, probably because of the excess of the  $d(-)$  in the crude syrup. This experience suggests that large yields of either form of active zinc ammonium lactate (3 to 4 times that separated by Purdie and Walker) can be obtained by their method of seeding a supersaturated solution if the initial lactic acid syrup contains an excess of the same active form as the seed added. The opposite form can also be obtained by seeding a virgin syrup, as in our case, but the yields are small. If the crude syrup contains a 20 per cent or greater excess of one active form, the preferable method for obtaining a large quantity of the pure isomer, which is in excess, is distillation and crystallization from the mixed ethers as described above, without previous precipitation of the active zinc ammonium salt.

The  $l(+)$  seed was prepared as follows: A quantity of zinc  $l(+)$ -lactate was converted to the ammonium salt by treatment with  $H_2S$ , followed by ammonia, and was then added to twice the equivalent quantity of lactate in the form of the zinc salt. The combined solutions were concentrated on the water bath to a syrup, and then cooled. The short rectangular prisms of the active double salt obtained were separated from the syrup by suction filtration, washed with 95 per cent alcohol, and air-dried. The  $d(-)$  seed was obtained by means of the morphine salt by Patterson and Forsyth's modification (6) of the method of Irvine (7).

The following was the typical method of preparation of the active acid from its double salt. 500 gm. of zinc ammonium  $d(-)$ -lactate were dissolved in 1200 cc. of cold water and filtered imme-

diately. The clear filtrate was set away overnight at about 2°. The next morning the precipitate of zinc lactate was separated by suction filtration and washed with distilled water until the washings no longer gave a positive test with Nessler's reagent. The salt was air-dried to constant weight and its water of crystallization determined by heating at 100° to constant weight. The theoretical value for the optically active form is 12.9 per cent, corresponding to 2 molecules of water of crystallization. The *dl* form contains 3 molecules of water of crystallization. When the water of crystallization was greater than 12.9 per cent, the salt was recrystallized until the theoretical value was obtained. If the zinc salt was pure from the outset, the collected filtrate and washings of ammonium lactate were boiled with  $\text{Ca}(\text{OH})_2$  to drive off the ammonia, and the free acid was obtained by precipitating the calcium with oxalic or sulfuric acid. If the zinc salt was impure, this free acid was converted to the zinc salt by boiling with zinc oxide, and then recrystallized until the theoretical percentage of water of crystallization was obtained. The free acid was liberated from the zinc salts by treatment with  $\text{H}_2\text{S}$ .<sup>2</sup> The combined aqueous solutions of the free acid were now concentrated at 60° with a water pump to a syrup, then distilled, and crystallized from the mixture of ethyl and isopropyl ethers as described above. In this manner about 120 gm. of free acid were obtained from about 500 gm. of each active double salt.

The purity of the free acids prepared, *i.e.* their freedom from anhydride, lactide, and water, was determined by titration with  $\text{N}/14$   $\text{NaOH}$  and phenolphthalein as indicator. The following standardized technique was employed. Between 0.4 and 1.0 gm. of the acid was transferred quickly to a tared weighing bottle, which was then covered, weighed, and inserted with tongs into a wide necked flask containing 100 cc. of  $\text{CO}_2$ -free distilled water.

<sup>2</sup> Free lactic acid is adsorbed in large quantities by such precipitates as zinc sulfide, calcium sulfate, and calcium oxalate, and boiling several times with large quantities of distilled water was necessary in order to avoid large losses. The precipitates were washed until the washings gave a negative reaction in the following test described by Denigès (8). 0.2 cc. of solution and 2 cc. of concentrated  $\text{H}_2\text{SO}_4$  are heated in a boiling water bath for 2 minutes. After cooling under the tap, a drop of an alcoholic solution of guaiacol is added. A fuchsin red color develops with 0.01 mg. of lactic acid.

The stopper was then shaken off the weighing bottle, and the titration begun with a stream of CO<sub>2</sub>-free nitrogen bubbling continuously through the solution. When the apparent end-point was reached, the weighing bottle and lid were removed with tongs and rinsed with CO<sub>2</sub>-free water, the rinsings being collected in the flask containing the lactic acid. The solution was now brought to a boil and again titrated to the first appearance of pink. The total alkali added to this point was designated as the first titration value. 5 cc. of N/14 NaOH were now added and the solution again boiled for 3 minutes, after which the remaining excess of alkali was back titrated with N/14 HCl. The addition of excess alkali, boiling, and back titration were repeated until the difference between the acid used and the alkali added in one back titration was not more than 0.2 cc. The difference between the total excess alkali added and the amount of N/14 HCl used in the back titration was noted as the back titration value. If lactide and anhydride are present (in the absence of a significant amount of water), the sum of the initial titration figure and the total acid liberated by boiling in excess of alkali is greater than the titration figure calculated on the assumption that the lactic acid weighed out was free of water, anhydride, or lactide. If  $T$  cc. of N/14 NaOH is the total titration figure observed per gm. of material weighed out, the percentage of free lactic acid is given by the formula  $\frac{172.7 - T}{17.3} \times 100$ , on the assumption that the only im-

purity is anhydride, and by the formula  $\frac{194.4 - T}{39} \times 100$  if the impurity is assumed to be solely lactide. Typical titration results with pure and impure lactic acids are given in Tables I and II.

Table III summarizes the melting points, dissociation constants, and hygroscopic properties of the pure acids. The melting point determinations were made on 10 to 12 gm. samples in a wide test-tube stirred constantly with dry nitrogen. The inside temperature was read with an Anschütz thermometer. The temperature of the water bath outside was kept about 1° higher than the inside during the melting, and 1° lower during the subsequent crystallization. The temperatures are the equilibrium temperatures observed during the melting when both phases were present. The crystallization temperatures were 1° lower. The melting points

of the pure active forms observed are much higher than the values of 25–27° given in Landolt-Börnstein (3) or the "International critical tables" (4), which are based on the work of Jungfleisch and Godchot (9). The low values found by these authors are probably to be attributed to incomplete resolution. This surmise is supported not only by the difference in the melting points, but also by the failure of other workers (7) and ourselves to obtain a satisfactory resolution by the method described by Jungfleisch and Godchot. The melting point of *dl*-lactic acid prepared by melting together and then crystallizing equal quantities of the

TABLE III  
*Summary of Some of the Properties of the Optically Active Lactic Acids*

Specimen	Melting point	Water absorbed from the air at room temperature; fraction of original weight	Dissociation constant at 25°
	°C.		<i>pK</i>
<i>d</i> (-)-Lactic acid from recrystallization of distillate (Specimen A)	52.7	0 in 4 hrs.; 2% in 20 hrs.	3.81 ± 0.01
<i>d</i> (-)-Lactic acid from zinc ammonium salt (Specimen B)	52.8	0 in 4 hrs.; 2% in 20 hrs.	3.83 ± 0.01
2 parts Specimen A + 1 part Specimen B	52.7		
<i>l</i> (+)-Lactic acid from zinc ammonium salt	52.8	1% in 4 hrs.; 3% in 20 hrs.	3.79 ± 0.01
Equal weights of Specimen A and <i>l</i> (+)-lactic acid	16.8	In liquid state 3% in 3 hrs.; 10% in 15 hrs.	3.81 ± 0.01

pure *l*(+) and *d*(-) acids was found to be 16.8°, nearly 1° lower than the melting point given by Krafft and Dyes for their *dl*-lactic acid. The probable explanation for this difference is that, apart from contamination with water or anhydro compounds, the product obtained by Krafft and Dyes was a mixture of the *dl* and one of the active forms. Such mixtures we have found melt at temperatures higher than 16.8°, according to the degree of excess of one of the active forms. The general experience has been that commercial lactic acid syrup, from which Krafft and Dyes obtained their product, contains nearly always an excess of one of



the active forms; and this mixed composition is carried over into the distillates.

The dissociation constants were determined in the usual manner by electrometric titration with Moloney hydrogen electrodes (10) in duplicate, against a saturated calomel half-cell. In the computation of the dissociation constants we have assumed the activity coefficient of the undissociated acid to be 1, which is justified by the freezing point data given in the "International critical tables." The activity of the lactate ions was estimated by the simplified form of the Debye-Hückel equation. The values obtained, there-

TABLE IV  
*Optical Rotations of Lactic Acid and Its Salts When  $\lambda = 5461 \text{ \AA.}$ , at 21-22°*

	Concentration	$\alpha$	$[\alpha]_{\text{Hg}}^{25}$	$[\text{M}]_{\text{Hg}}^{25}$
	<i>gm. per cent</i>	<i>degrees</i>		
<i>d</i> (-)-Lactic acid	8.00	+0.41	+2.6	+2.3
"    "	4.00	+0.18	+2.3	+2.1
<i>l</i> (+)-Lactic "    "	8.00	-0.41	-2.6	-2.3
"    "	4.00	-0.18	-2.0	-1.8
Zinc ammonium <i>l</i> (+)-lactate	8.00	-1.10	-6.9	-8.9
"    " <i>d</i> (-)-lactate	8.00	+1.10	+6.9	+8.9
Sodium <i>l</i> (+)-lactate	4.20	-1.15	-13.7	-15.8
" <i>d</i> (-)-lactate	7.05	+1.70	+12.1	+13.5

fore, approximate thermodynamic dissociation constants, pK (as distinguished from titration constants, usually designated as pK').

The avidity of the free acids for water was determined approximately by exposing a weighed quantity of the acid to the air at room temperature in an open weighing bottle. Table III shows that the pure optically active acids are only slightly hygroscopic. This also runs counter to the description usually given, which is derived from the papers of Jungfleisch and Godchot. As in the case of the difference in the melting points, the discrepancy probably is to be ascribed to incomplete resolution, and possibly also to contamination of the product obtained by these authors by water and anhydride, since the free acids were prepared from their

quinine salts by the distillation method of Krafft and Dyes, and were not purified further.

The pure optically active acids are relatively quite stable. Kept in a desiccator at room temperature, both forms remained unchanged for more than a month; after 6 months, only a small amount of anhydride formation was found to have occurred. The second group of figures in Table II shows that only a small amount of anhydride formation occurs during the melting of the crystals.

The rotations of the free acids and their salts are given in Table IV. The measurements were made at 21–22° in a 2 dm. tube, with the mercury green line ( $\lambda$  5461 Å.). The difference in the specific rotations of the two sodium salts is the usual effect of changing the concentration.

The biological activity of the two optically active forms was tested with lactic acid dehydrogenase prepared from muscle by the method of von Szent-Györgyi (11). When the *l*(+) form was added to the enzyme and methylene blue in an evacuated Thunberg vessel, the dye was quickly decolorized. The *d*(–) form, on the other hand, was quite inactive, giving a longer decoloration time than the enzyme alone. We are indebted to the kindness of Mr. H. F. Schott for this examination of the two forms of lactic acid prepared, and for his active interest and many helpful suggestions throughout the course of this work.

#### SUMMARY

1. Two methods are described for obtaining optically active lactic acid (both isomers) from a commercial aqueous syrup.
2. A method is described of preparing the active isomers in a crystalline state, free of water, anhydride, and lactide.
3. Some of the properties of the crystalline acids are described. The following physical constants are given: melting points, *l*(+)-lactic acid, 52.8°; *d*(–)-lactic acid, 52.8°; *dl*-lactic acid, 16.8°; the acid dissociation constant of the three forms at 25° is  $pK = 3.81 \pm 0.02$ .

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# Low temperature crystal structure and molecular conformation of L-(+)-lactic acid

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## Abstract

L-(+)-Lactic acid,  $C_3H_6O_3$ ,  $M_r = 90.08$ , orthorhombic,  $P2_12_12_1$ ,  $a = 5.4896(3)$ ,  $b = 8.4221(3)$ ,  $c = 9.3453(5)$  Å,  $V = 432.07(4)$  Å<sup>3</sup>,  $Z = 4$ ,  $D_x = 1.385$  g cm<sup>-3</sup>,  $\lambda(MoK\alpha) = 0.71073$  Å,  $\mu = 1.2$  cm<sup>-1</sup>,  $F(000) = 192$ .

Diffraction data have been collected at 100 K and the structure has been solved by direct methods to  $R = 0.030$  for 976 unique observed data. The hydroxyacetic acid moiety of the molecule is almost planar with the aliphatic hydroxy-group oxygen atom at the side of the carbonyl oxygen atom of the carboxy group. The two hydroxy groups are involved in intermolecular hydrogen bonding. The aliphatic hydroxy group forms a bifurcate planar hydrogen-bond configuration in which the aliphatic hydroxy and acid carbonyl oxygen atoms of a symmetry-related molecule participate as acceptors. The acidic hydroxy group donates an intermolecular hydrogen bond to the aliphatic hydroxy-group oxygen atom.

## 1. Introduction

L-(+)-Lactic acid is a biologically important substance and the history of its study by the early chemists is closely linked to the development of the concept of optical activity [1]. L-(+)-Lactic acid is also an important end product of the anaerobic metabolism of many micro-organisms and animals such as molluscs and vertebrates.

It is curious that in spite of its well-established and important role, so far no crystal structure has been reported for this simple metabolite. The absence of crystal structure data of L-(+)-lactic acid is certainly related to the problems inherent in obtaining single crystals. The preparation

of such crystals is seriously hampered by the formation on prolonged standing of lactic acid oligomers by condensation polymerization. However, we have succeeded in obtaining single crystals of good quality by cooling an aqueous solution. We now report the crystal structure of L-(+)-lactic acid.

## 2. Experimental

A colourless crystal with dimensions  $0.75 \times 0.35 \times 0.35$  mm was used for data collection on an Enraf-Nonius CAD-4 diffractometer with Zr-filtered  $MoK\alpha$  radiation. As the crystals of the compound are very hygroscopic, the structure analysis was carried out at low temperature by placing the crystal in a stream of gaseous nitrogen

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with a temperature of about 100 K. This procedure proved to be excellent for the prevention of deterioration of the crystal by uptake of water. Lattice parameters were determined from the setting angles of 25 reflections in the range  $12.20 \leq \theta \leq 19.58^\circ$ . The diffracted intensities of 1508 reflections were collected with the  $\omega - 2\theta$  scan mode,  $\Delta\omega = (0.62 + 0.35 \tan \theta)^\circ$ ,  $2\theta_{\max} = 55^\circ$ , and  $-7 \leq h < 7$ ,  $0 \leq k \leq 10$ ,  $-12 \leq l \leq 0$ , of which 976 were unique ( $R_{\text{int}} = 0.012$ ). Three periodically measured standard reflections ( $-2\ 1\ -2$ ,  $-3\ 2\ 0$  and  $0\ 2\ -2$ ), measured every 20 min, showed an average deviation of less than 2% during 11 h of X-ray exposure. Intensities were corrected for Lp (Lorentz polarization) effects but not for absorption. The structure was solved in space group  $P2_12_12_1$  by direct methods using the program SHELXS86 [2].

Hydrogen atoms were located from difference Fourier maps and treated with an overall isotropic thermal parameter which refined to  $0.026(2)\text{\AA}^2$ . Anisotropic full-matrix least-squares refinement based on  $F^2$  of 74 parameters converged to  $R$  (on  $F$ ) = 0.030 and  $wR$  (on  $F^2$ ) = 0.074 for all data, with  $w = [\sigma^2(F_o^2) + (0.0435p)^2 + 0.0562p]^{-1}$  where  $p = (F_o^2 + 2F_c^2)/3$ ,  $S = 1.09$ , and  $(\Delta/\sigma)_{\max} = -0.001$ . Maximum and minimum residual densities in the final difference map were 0.28 and  $-0.15\text{ e}\text{\AA}^{-3}$ , respectively. The atomic scattering factors were taken from International Tables for

X-ray Crystallography [3]. The refinements were performed with the SHELXL92 program [4] and the EUCLID package [5] was used for the calculation of geometries and preparation of the illustration. All calculations were carried out on an ULTRIX DEC system-5000.

### 3. Discussion

The final atomic coordinates with equivalent isotropic thermal parameters for C and O atoms and a general isotropic thermal parameter for H atoms are listed in Table 1; the molecular geometry (distances, angles and selected torsion angles) are given in Table 2. A projection of part of the structure showing the hydrogen-bond network is portrayed in Fig. 1.

The carboxy-group geometry displays the characteristics of perfect ordering as follows from the C–O distances of 1.320(1) and 1.208(1) Å and C–C–O angles of 111.9(1) and 124.2(1)°, with the larger angle associated with the shorter C–O distance. The C1–C2 bond is short, 1.519(1) Å, which has often been observed in carboxylic acids [6,7], and the C2–C3 and C2–O3 bonds are normal with lengths of 1.521(2) Å and 1.425(1) Å, respectively. The C–H distances average to 0.98 Å and the two O–H distances are shortened (0.79(2) and

Table 1

Fractional atomic coordinates and equivalent isotropic thermal parameters ( $\text{\AA}^2$ ) of C and O atoms with esds in parentheses. The hydrogen atoms have an overall isotropic thermal parameter

	x	y	z	$U(\text{eq})^a$
O (1)	0.6162 (2)	0.4279 (1)	0.2898 (1)	0.0183 (3)
O (2)	0.8700 (2)	0.5956 (1)	0.1804 (1)	0.0222 (3)
O (3)	0.5535 (2)	0.6620 (1)	-0.02253 (9)	0.0150 (2)
C (1)	0.6735 (2)	0.5318 (1)	0.1895 (1)	0.0131 (3)
C (2)	0.4615 (2)	0.5635 (1)	0.0891 (1)	0.0131 (3)
C (3)	0.3492 (3)	0.4116 (2)	0.0307 (2)	0.0204 (3)
H (1)	0.727 (4)	0.411 (2)	0.342 (2)	0.026 (2)
H (2)	0.341 (3)	0.620 (2)	0.144 (2)	0.026 (2)
H (3)	0.451 (4)	0.727 (2)	-0.046 (2)	0.026 (2)
H (3A)	0.279 (3)	0.352 (2)	0.116 (2)	0.026 (2)
H (3B)	0.218 (3)	0.441 (2)	-0.032 (2)	0.026 (2)
H (3C)	0.470 (3)	0.352 (2)	-0.024 (2)	0.026 (2)

<sup>a</sup>  $U_{\text{eq}} = \frac{1}{3} \sum_i \sum_j U_{ij} a_i^* a_j^* a_i \cdot a_j$ .

Table 2

Bond distances (Å), bond angles (deg) and selected torsion angles (deg) with esds in parentheses

O(1)–C(1)	1.320(1)	O(3)–H(3)	0.82(2)
O(2)–C(1)	1.208(1)	C(2)–H(2)	0.96(2)
O(3)–C(2)	1.425(1)	C(3)–H(3A)	1.02(2)
C(1)–C(2)	1.519(1)	C(3)–H(3B)	0.96(2)
C(2)–C(3)	1.521(2)	C(3)–H(3C)	0.98(2)
O(1)–H(1)	0.79(2)		
O(1)–C(1)–O(2)	123.9(1)	C(1)–C(2)–H(2)	107(1)
O(1)–C(1)–C(2)	111.87(9)	C(3)–C(2)–H(2)	109(1)
O(2)–C(1)–C(2)	124.24(9)	C(2)–C(3)–H(3A)	107(1)
O(3)–C(2)–C(1)	106.44(9)	C(2)–C(3)–H(3B)	108(1)
O(3)–C(2)–C(3)	111.7(1)	C(2)–C(3)–H(3C)	110(1)
C(1)–C(2)–C(3)	112.60(9)	H(3A)–C(3)–H(3B)	109(1)
C(1)–O(1)–H(1)	112(1)	H(3A)–C(3)–H(3C)	114(1)
C(2)–O(3)–H(3)	110(1)	H(3B)–C(3)–H(3C)	109(2)
O(3)–C(2)–H(2)	110(1)		
O(1)–C(1)–C(2)–O(3)	–173.49(8)		
O(1)–C(1)–C(2)–C(3)	–50.7(1)		
O(2)–C(1)–C(2)–O(3)	7.6(1)		
O(2)–C(1)–C(2)–C(3)	130.4(1)		

0.82(2) Å) as is typical for structures determined by X-ray diffraction.

The hydroxyacetic acid moiety is almost planar as is indicated by the torsion angle O2–C1–C2–O3 of 7.6(1)° and  $\sigma_{\text{plane}}$  of 0.054 Å, and the O atom of the aliphatic hydroxy group is at the side of C=O.

of the carboxy group which is usual in  $\alpha$ -hydroxy acids [8].

The two hydrogen-bond donors, O1–H1 and O3–H3, are involved in intermolecular hydrogen bonding. The acidic O1–H1 donor interacts strongly with O3 of a symmetry-related molecule

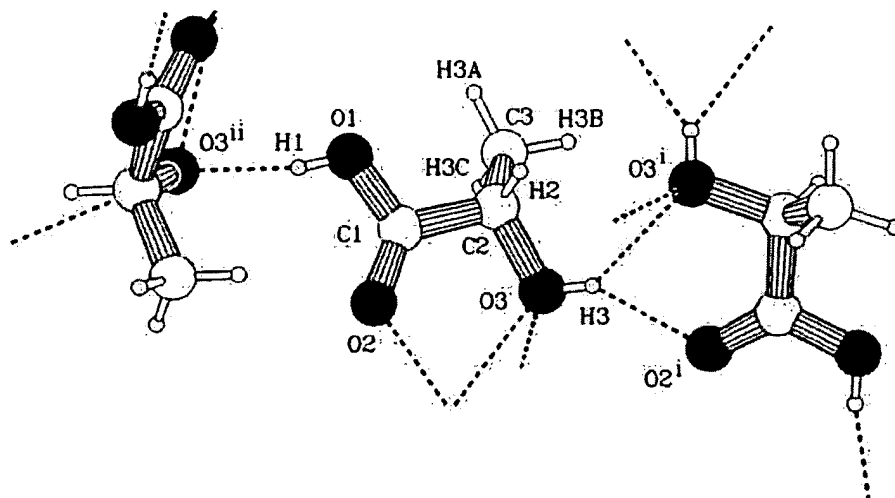


Fig. 1. Projection of part of the structure with atom numbering, showing the hydrogen-bond network. Symmetry code: (i)  $-\frac{1}{2} + x$ ,  $\frac{1}{2} - y$ ,  $-z$ ; (ii)  $\frac{1}{2} - x$ ,  $1 - y$ ,  $\frac{1}{2} + z$ .

at  $1\frac{1}{2} - x$ ,  $1 - y$ ,  $\frac{1}{2} + z$  with O1...O3 2.634(1) Å, H3...O3 1.85(2) Å and O1-H1...O3 168(2)°. The aliphatic hydroxy group O3-H3 participates in a symmetrical bifurcate (three centre) hydrogen bond by interaction with the carbonyl O2 atom of the acid group and O3 of the aliphatic OH group of a symmetry-related molecule at  $-\frac{1}{2} + x$ ,  $1\frac{1}{2} - y$ ,  $-z$ . The geometry of this four-atom configuration is as follows: O3...O2 2.713(1) Å, H3...O2 2.00(2) Å and O3-H3...O2 145(2)°, and O3...O3 3.148(1) Å, H3...O3 2.46(2) Å and O3-H3...O3 143(2)°. This configuration is planar as can be deduced from the sum of angles of 360(3)° around the hydrogen atom.

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